From Einstein to Lenz: A Relativistic Perspective on Electromagnetic Induction

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Abstract

In most introductory courses on electromagnetism, undergraduate students accept the idea that the electric and magnetic fields are independent entities. One of the reasons why it happens could be related to the duration of the program: when it is time to unity them, the semester is over. Usually, in textbooks used in these courses, first, the student learns about the electric field separately before the magnetic field. It's only after that the Maxwell's equations and their applications are introduced, suggesting a liaison with electric and magnetic phenomena on either side. Yet the connection between these allegedly different topics is not explored.

On the other hand, it is only in advanced courses and textbooks on electromagnetism that the students truly learn about the nature of electric and magnetic fields and their behavior as a unified entity. We need to reconsider the current approach to teaching these concepts and explore the possibility of introducing such formulations in primary-level courses (i.e., courses that teach elementary concepts of specific topics in physics at the college level).

Up to our knowledge, it is not explicitly addressed in other works in literature how the Lorentz transformations of the electromagnetism field tensor $\mathcal{F}^{\mu}{}_{\nu}$ play a crucial role in unifying the electric and magnetic fields, giving birth to the induction/Lenz's law. On one hand, works in literature either focus their approach on demonstrating the lack of covariance of Maxwell equations and the Lorentz force under Galilean transformations, or on alternative approaches to evince electromagnetism covariance under Lorentz transformation. On the other hand, what sets our work apart is the primary emphasis on the relativistic origin of Lenz's law, based on the transformation rule of the tensor $\mathcal{F}^{\mu}{}_{\nu}$.

In this work, we aim to propose a didactic approach that demonstrates the unified nature of the electric and magnetic fields to primary electromagnetism students at undergraduate level, anchoring in the principles of special relativity and the coordinate transformation of $\mathcal{F}^{\mu}{}_{\nu}$. In particular, we show how the Lenz's law can be found invoking the principle of relativity.

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